REMARKS

Applicant thanks the Examiner for the careful consideration given to this application. Reconsideration and allowance are now respectfully requested in view of the following remarks. Claims 1, 3-13, 15-17 and 19-24 are pending in this application. Claims 1, 13, 17 and 21 are independent claims.

Claim Rejections Under 35 U.S.C. §103

Claims 1, 3, 4, 6-13, 15, 17, 19, 21, 22 and 24 stand rejected under 35 U.S.C. §103(a) as being unpatentable over U.S. Patent Publication No. 2001/0055356 to Davies (hereinafter "Davies") in view of U.S. Patent Publication No. 2005/0031051 to Rosen et al. (hereinafter "Rosen"), and further in view of U.S. Patent Publication No. 2001/0029523 to Mcternan et al. (hereinafter "Mcternan"). This rejection is respectfully traversed.

Applicants will first restate their previously-presented arguments, submitted on October 2, 2009. In particular, Applicants submit that the combination of Davies, Rosen and Mcternan does not teach or suggest the combination of elements recited in claims 1, 3, 4, 6-13, 15, 17, 19, 21 and 22. Independent claims 1 and 21, in part, recite "foregoing retransmission of the data packet when said number of consecutive times exceeds a predetermined threshold and when the detecting step detects an acknowledgement transmission from the each of the plurality devices except for said particular device."

Independent claim 13, in part, recites "forego retransmission of the data packet when said number of consecutive times exceeds a predetermined threshold and when an acknowledgement transmission from the each of plurality devices except for said particular device is detected."

Independent claim 17, in part, recites "means for foregoing retransmission of the data packet when said number of consecutive times exceeds a predetermined threshold and when said means for detecting detects an acknowledgement transmission from the each of the plurality devices except for said particular device." As acknowledged in the Office Action, the combination of Davies and Rosen does not teach or suggest these features.

Mcternan does not cure the deficiencies of Davies and Rosen. Paragraph 0071 of Mcternan further discloses that

> The Media Player 376 issues requests for media packets 352 to a server 338 or 364. If the server 338 or 364 is multicasting the content, the client request takes the form of a subscription to the router 372. Packets are received across the network 368 via the client's network interface adapter. The Media Player 376 or other application requesting data from the server accepts and records receipt of packets in memory. Upon receipt of a duplicate packet, the client will stop receiving further packets, as the receipt of a duplicate packet is an indication that the packet sequence has looped around to the point at which the client first starting receiving packets and therefore the client should have received al the packets in the sequence. The client checks whether any packets in the sequence are missing and, if so, determines if the time to wait for the Looping Data Sender 350 to retransmit the packet is greater than a time threshold, such as the time needed to directly request and receive the missing packet or packets from the server, or a predefined threshold set by the content producer. If the time to wait for the packet to be received is greater than the threshold, the Download Manager 378 issues a request to the Client Request Handler 356. Upon receiving the request, the Client Request Handler 356 accesses the Looping Data Sender 350, duplicates the requested packet and transmits it to the client 336. The result is that <u>clients are continually fed a stream of requested data and can recover missing packets by either simply awaiting retransmission of the packet or requesting it directly, whichever the client deems is most efficient given the bandwidth constraints of the client</u>. (underlining added)

So according to paragraph 0071 of Mcternan, if the client does not receive a packet, there is no foregoing of future transmission, as recited in the pending claims. Instead, the client either waits for retransmission of the missing packet or directly requests transmission of the missing packet. Unlike what is alleged on page 4 of the Office Action, that is, that Mcternan discloses foregoing retransmission, Mcternan discloses that the client requests retransmission in two ways – one, that the client determines if the time to wait for retransmission is greater than a predefined threshold, then the client makes the request instead of waiting for the time for retransmission; and two, that the client determines if the time to wait for retransmission is less than a predefined threshold, then the client simply waits for the time for retransmission. In either method as disclosed by Mcternan, retransmission is requested. There is no teaching or suggestion in the cited sections of Mcternan of foregoing retransmission, as alleged in the Office Action.

Claims 1 and 21, on the other hand, recite "foregoing retransmission of the data packet when said number of consecutive times exceeds a predetermined threshold <u>and</u> when the detecting detects an acknowledgement transmission from the each of the plurality devices except for said particular device." (underlining added) Claims 13 and 17 recite similar features, as

noted above. So according to the pending claims, transmission is foregone when (1) "said number of consecutive times exceeds a predetermined threshold" and (2) "the detecting detects an acknowledgement transmission from the each of the plurality devices except for said particular device."

In addition, in Mcternan, it is the client who waits for retransmission of the missing packet or directly requests transmission of the missing packet. In the pending claims, on the other hand, the foregoing transmission is perform by the receiving device. Therefore, the actors that allegedly forego transmission, in Mcternan, are different from those recited in the pending claims.

Although on page 4, the Office Action acknowledged that Davies does not teach or suggest the foregoing element, as recited in the pending claims, and the Office Action cited Mcternan to cure these deficiencies, in the Response to Arguments section, the Office Action alleged that Davies also discloses that retransmission is suppressed (foregone) when the validity of the data has expired (allegedly "a predetermined time threshold"). Applicants submit that even though the cited sections of Davies discloses that retransmission is suppressed when the validity of the data has expired, there is no teaching or suggestion in Davies that such suppression is performed after comparing the alleged "predetermined time threshold" with "the number of consecutive times an acknowledgement packet is not received from a particular one of the plurality of devices" and when "when said number of consecutive times exceeds" the "predetermined time threshold." Therefore, Davies also fails to teach or suggest "foregoing retransmission of the data packet <u>when said number of consecutive times exceeds a predetermined threshold</u>," as recited in the pending claims. (underlining added)

Furthermore, as noted on page 4 of the Office Action, there is no teaching or suggestion in Davies of "foregoing retransmission of the data packet when ... the detecting detects an acknowledgement transmission from the each of the plurality devices except for said particular device," as recited in the pending claims. So Davies fails to teach or suggest both conditions recited in the pending claims for foregoing transmission.

Moreover, the suppression of retransmission, as disclosed in paragraph 0021 of Davies would be impossible according the disclosure of paragraph 0071 of Mcternan. As discussed above, in Mcternan, the client either waits for retransmission of the missing packet or directly

requests transmission of the missing packet. So in Mcternan, one would not have the "predetermined time threshold" of Davies, as Mcternan would request retransmission before such "predetermined time threshold" occurs.

Turning now to the Advisory Action mailed October 23, 2009, this Advisory Action asserts that Rosen overcomes these deficiencies. In particular, the Advisory Action states,

> [T]he applicant argues that none of the references disclose[s] foregoing retransmission of the data packet when said number of consecutive times exceeds a predetermined threshold and when the detecting step detects an acknowledgment transmission from each of the plurality [of] devices except for said particular device. The examiner respectfully disagrees with the applicant's statement and asserts that a retransmission occurs because an acknowledgement [*sic*] is not received (Rosen, par. 131, lines 5-13). Rosen also discloses that retransmission is foregone/stopped when a predetermined threshold is reached (par. 131, lines 5-13).

Advisory Action at page 2 ("Continuation Sheet"). While Applicants respectfully disagree with these characterizations of Rosen, it is also believed that Rosen is improperly applied for the following further reasons.

Rosen (U.S. Patent Application Publication No. 2005/0031051) is based on U.S. Applicant No. 10/910,919, filed on August 3, 2004. This application claims the priority benefit of two U.S. Provisional Patent Applications, 60/492,628, filed on August 4, 2003, and 60/529,152, filed on December 11, 2003. Note that the filing date of the present application is September 12, 2003. Therefore, in order to qualify as prior art, the teachings of Rosen being applied must have been presented in the provisional patent application filed on August 4, 2003. However, a review of U.S. Provisional Patent Application No. 60/492,628 shows that the material being relied upon, at least by the Advisory Action, was ***not*** disclosed in that provisional application. Therefore, this material is ***not*** entitled to the August 4, 2003 priority date and ***cannot be cited as prior art against the present claims***. A copy of the U.S. Provisional Patent Application is being furnished with this response, as a courtesy to the Examiner.

Applicants further note that the Advisory Action contains no further reasons (other than the cited portions of Rosen) for disagreement with the previously-presented arguments, restated

above. Hence, it is respectfully submitted that the Advisory Action fails to refute those arguments, and Applicants continue to assert their validity.

Therefore, the combination of Davies, Rosen and Mcternan does not teach or suggest "foregoing retransmission of the data packet when said number of consecutive times exceeds a predetermined threshold and when the detecting step detects an acknowledgement transmission from the each of the plurality devices except for said particular device," as recited in the pending claims.

Based on the distinctions noted above, Applicants respectfully submit that the cited references do not teach or suggest the combination of elements recited in claims 1, 13, 17 and 21. Each of claims 3, 4, 6-12, 15, 19 and 22 depends on claims 1, 13, 17 and 21, and thus incorporates all of the elements of claims 1, 13, 17 and 21, in addition to the further limitations recited in claims 3, 4, 6-12, 15, 19 and 22. Hence, claims 3, 4, 6-12, 15, 19 and 22 are also allowable at least because of their dependence on claims 1, 13, 17 and 21. Therefore, Applicants respectfully request that this rejection of claims 1, 3, 4, 6-13, 15, 17, 19, 21, 22 and 24 under 35 U.S.C. §103 be withdrawn.

Claims 5, 16, 20 and 23 stand rejected under 35 U.S.C. §103(a) as being unpatentable over Davies et al. in view of Rosen, in view of Mcternan, and in further view of U.S. Patent Publication No. 2002/0136268 to Gan et al. (hereinafter "Gan"). This rejection is respectfully traversed.

Each of claims 5, 16, 20 and 23 depend on claims 1, 13, 17 and 21, and thus, incorporates each of the elements of these claims. Gan does not cure the deficiencies of Davies and Rosen (and/or Mcternan), as outlined above. Specifically, Gan does not teach or suggest "foregoing retransmission of the data packet when said number of consecutive times exceeds a predetermined threshold and when said means for detecting detects an acknowledgement transmission from the each of the plurality devices except for said particular device," as recited in 1, 13, 17 and 21 upon which claims 5, 16, 20 and 23 depend. Therefore, Applicants respectfully request that this rejection of claims 5, 16, 20 and 23 under 35 U.S.C. §103 be withdrawn.

Disclaimer

Applicants may not have presented all possible arguments or have refuted the characterizations of either the claims or the prior art as found in the Office Action. However, the lack of such arguments or refutations is not intended to act as a waiver of such arguments or as concurrence with such characterizations.

CONCLUSION

In view of the above, consideration and allowance are respectfully solicited.

In the event the Examiner believes an interview might serve in any way to advance the prosecution of this application, the undersigned is available at the telephone number noted below.

The Office is authorized to charge any necessary fees to Deposit Account No. 22-0185.

Applicant believes no fee is due with this response. However, if a fee is due, please charge our Deposit Account No. 22-0185, under Order No. 27592-00431-US from which the undersigned is authorized to draw.

Dated: November 4, 2009

Respectfully submitted,

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17302 U.S. PTO
60/492628
08/04/03

PROVISIONAL APPLICATION FOR PATENT
COVER SHEET

Case Docket No. ROSEN.004PR
Date: August 4, 2003

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I hereby certify that this paper together with enclosures is being deposited with the United States Postal Service "Express Mail Post Office to Addressee" service under 37 CFR 1.10 on the date indicated below and is addressed to Mail Stop Provisional Patent Application, Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.

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Date of Deposit: **Monday, August 04, 2003**

By
Robert F. Gazdzinski
Reg. No. 39,990

Sir:

This is a request for filing a PROVISIONAL PATENT APPLICATION under 37 C.F.R. § 1.53(c):

For: **ENHANCED HOLOGRAPHIC COMMUNICATIONS APPARATUS AND METHOD**

Full Name of sole or first inventor: Lowell Rosen

Residence: 7941 Paseo del Ocaso, La Jolla, California 92037

Citizenship: **UNITED STATES**

Enclosed are:

(X) Specification in twenty-eight (28) pages, including claim page, and abstract.

(X) Appendix I (12 pages).

(X) Ten (10) sheet(s) of informal drawings including thirteen (13) figures.

(X) Applicant claims small entity status. (See 37 CFR 1.27).

(X) A check in the amount of $80.00 to cover the filing fee is enclosed.

(X) The Commissioner is hereby authorized to charge any additional fees under 37 CFR 1.16 and 1.17 which may be required, or credit any overpayment to Deposit Account No. 501423. A duplicate copy of this sheet is enclosed.

Was this invention made by an agency of the United States Government or under a contract with an agency of the United States Government?

(X) No.

The PTO did not receive the following listed item(s) 28 pages of Spec -
We received 26 pages.

PROVISIONAL APPLICATION FOR PATENT
COVER SHEET

(X) Please send correspondence to:

Gazdzinski & Associates
Attn:. Robert F. Gazdzinski, Esq.
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Respectfully submitted,

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ENHANCED HOLOGRAPHIC COMMUNICATIONS APPARATUS AND METHOD

1. Field of the Invention

This invention relates generally to the field of communications, and more specifically to, *inter alia,* secure and covert modulated communications systems, such as those having the characteristics of random noise.

Summary of the Invention

In a first aspect of the invention, improved methods and apparatus for providing simultaneous use by multiple users of a single holographic communications phase code is disclosed. In one embodiment, each user is assigned a unique offset frequency but common phase code.

In a second aspect of the invention, a method for increasing the data transfer rate in the spread bandwidth is disclosed. In one embodiment, base band pages are assigned unique frequency offsets but common phase code.

In a third aspect of the invention, a method for correcting multipath distortion is provided. In one embodiment, a filter is utilized to remove the distortion. In a second embodiment, the distortion is removed utilizing dc measurements.

In a fourth aspect of the invention, frequency-hopping spread spectrum (FHSS) techniques are applied to the holographic carrier air interface (or other bearer medium) to effectuate further randomness, additional processing gain and covertness.

In a fifth aspect of the invention, the transmitted holographic carrier, transmitted over an air interface or other bearer medium, consists of either the complex holographic signal (real and imaginary parts), or the real or imaginary part alone. The receiver then substitutes a signal of all zeros for the missing part. This simplifies both transmitter and receiver hardware and decreases signal processing requirements.

In a sixth aspect of the invention, an improved tracking device utilizing holographic communication techniques is disclosed. In one embodiment, the device comprises a microprocessor, a hologram communications transmitter, memory, and GPS receiver. This device can transmit accurate location information, data and voice, while maintaining a high

degree of covertness. The device can also store pre-calculated holographic signal waveforms (in digital form) already phase code spread and transformed, and ready for transmission. Such waveforms can represent, for example, a pre-determined library of rescue, alert, warning, departure and arrival messages. Such messages can be sent out over a carrier air interface (or other bearer medium) covertly with a single key-press, thus saving significant processor computation time.

In a seventh aspect of the invention, an improved holographic communications method is disclosed. In one embodiment, the holographic communications methods described above are adapted to facilitate use by acoustic systems such as sonar or underwater communications. In another embodiment, radar systems are adapted to use the holographic techniques. In yet another embodiment, light (coherent/non-coherent), gamma rays and X-rays and atomic particle beams are used as the bearer medium.

Brief Description of the Drawings

The features, objectives, and advantages of the invention will become more apparent from the detailed description set forth below when taken in conjunction with the drawings, wherein:

Figs. 1a and 1b are graphical representations of Gaussian and exemplary binary pulsed waveforms, respectively, according to the invention.

Figs. 2a and 2b are graphical representations of Gaussian and exemplary "sharp" (short duration) pulsed waveforms, respectively, according to the invention.

Figs. 3a and 3b are functional block diagrams of exemplary multi-user holographic transmitter and receiver processes, respectively, according to the invention.

Figs. 4a and 4b are functional block diagrams of exemplary multi-data page holographic transmitter and receiver processes, respectively, according to the invention.

Fig. 5 is a graphical representation of an exemplary "all-real" phase coder according to the invention.

Figs. 6a and 6b are graphical representations of one-channel (one data, one reference) and exemplary two-channel (two data channels with Sin(x)/x distribution) pulsed waveforms, respectively, according to the invention.

Fig. 7 is graphical representations of an exemplary embodiment of a multi-path distortion removal technique according to the invention.

Fig. 8 is a front perspective view of an exemplary embodiment of a portable miniature transceiver device according to the invention.

Detailed Description of the Preferred Embodiment

Reference is now made to the drawings wherein like numerals refer to like parts throughout.

As used herein, the terms "hologram" and "holographic" refer to any waveform, regardless of physical medium (e.g., electromagnetic, acoustic/sub-acoustical or ultrasonic, matter wave, gravity wave, etc), which has holographic properties.

As used herein, the term "digital processor" is meant generally to include all types of digital processing devices including, without limitation, digital signal processors (DSPs), reduced instruction set computers (RISC), general-purpose (CISC) processors, microprocessors, and application-specific integrated circuits (ASICs). Such digital processors may be contained on a single unitary IC die, or distributed across multiple components. Exemplary DSPs include, for example, the Motorola MSC-8101/8102 "DSP farms", the Texas Instruments TMS320C6x, or Lucent (Agere) DSP16000 series.

As used herein, the term "display" means any type of device adapted to display information, including without limitation CRTs, LCDs, TFTs, plasma displays, LEDs, and fluorescent devices.

As used herein, the term "base band" refers to the band of frequencies representing an original signal to be communicated.

As used herein, the term "carrier wave" refers to the electromagnetic or other wave on which the original signal is carried. This wave has a frequency or band of frequencies (as in spread spectrum) selected from an appropriate band for communications transmission or other functions (such as detection, ranging, etc.).

It is noted that while portions of the following description are cast in terms of RF (wireless) communications applications, the present invention may be used in conjunction with any number of different bearer mediums and topologies (as described in greater detail subsequently herein). Accordingly, the following discussion is merely exemplary of the broader concepts of the invention.

Overview

Co-owned U.S. Patent Number: 4,972,480, issued Nov. 20, 1990 and entitled "Holographic Communications Device and Method" (hereinafter "the '480 patent"), which is incorporated herein by reference in its entirety (Appendix I hereto), discloses an improved secure and covert modulated radio frequency carrier wave communications system of a holographic nature. This system was designed to produce transmissions having the characteristics of random noise and a high degree of information redundancy characteristic of diffuse image holograms. In effect, it produces a signal appearing as noise in both the time and frequency domains. Desirable characteristics of the basic holographic technology include: (i) a high degree of covertness; (ii) a lack of data frame registration (i.e., the inverse Fourier Transform of F(t) is f(w), therefore the inverse transform of F(t-T) is $f(w)e^{iwT}$, where F(t-T) is the delayed hologram frame, and $f(w)e^{iwT}$ is the registered base band frame which is frequency shifted); (iii) rapid receiver acquisition and de=spreading (due to aforementioned lack of registration); (iv) great channel robustness (i.e., hologram RF signals can survive very high percentage losses through inherent redundancy afforded by convolution of code and base band spectrums); and (v) the ability to receive and decode parts of multiple holograms (i.e., hologram received in receiver time window t is $F'_1(t-T_1) + F'_2(t-T_2)$, with base band of $f_1(w)^{eiwT_1}+f_2(w)^{eiwT_2}$; multiplication by $e^{-|Code|}$ de-spreads frame 1, while frame 2 appears as wideband noise, and a narrowband filter can be used to recover frame 1).

While the technology of the '480 patent is clearly useful and provides many intrinsic benefits as described, further improvements are possible, and the technology expanded in terms of the scope and types of applications with which it may be used.

Accordingly, the present invention provides several enhancements and improvements to the basic technology disclosed in the '480 patent, as well a variety of new applications therefor. Such enhancements include, *inter alia*, the use of a spectrum spreading techniques (e.g., frequency hopping spread spectrum, or FHSS), and use of multiple base band modulations including, e.g., frequency modulation, amplitude modulation, various types of pulse modulation, etc., for the purpose of adding a multitude of simultaneous users and a multitude of simultaneous "pages" of information all within a single covert and noise-like transmission.

Furthermore, the present invention also teaches an improved technique by which more information can be carried on the waveform through assignment of the dc base band channel (described in the '480 patent) to an information-modulated waveform.

Yet further enhancements include the use of random time-dithered waveforms, to foil eavesdroppers using correlation-based intercept receivers.

New uses of the holographic technology include the application to other information carrying sources of energy such as coherent and incoherent light sources, x-rays, and even gamma rays, mechanical sources of energy (such as acoustical and other sonic waves outside the range of human hearing), and finally to matter waves such as subatomic particle beams. This broad range of media allows the technology to be applied to e.g., any number of communications, radar, and sonar-based devices.

Enhancements to Holographic Technology

The output radio frequency waveforms of the '480 Patent are generally confined to the bandwidth established by the base band signals and the modulating noise waveform. Although this may be sufficient for certain applications, certain uses (e.g., military, or high density civilian communications systems such as those used in a metropolitan area) generally require a wider spread of bandwidths. Accordingly, one aspect of the present invention applies a frequency hopping approach to the radio hologram output waveform. Frequency hopping is a well known RF spread-spectrum technique wherein, e.g., a pseudo-random hop sequence is generated by a seeded algorithm, the sequence being dependent in large part on the seed. The carrier accordingly hops from one frequency to the next, disposing either more ("fast" FHSS) or less than ("slow" FHSS) one temporal "chip" of data (e.g., bit, byte, etc., typically measured in the temporal hop duration) per hop. The receiver is synchronized to the same sequence, such as by using a similar pseudo-random algorithm and "seed".

In the context of the present invention, frequency hopping of the hologram output waveform advantageously spreads the bandwidth further than without such hopping. This increases the processing gain of the holographic waveform by a factor proportional to the ratio of the frequency hopped bandwidth and the holographic waveform bandwidth. Accordingly, the frequency-hopped holographic signal has enhanced resistance to jamming, and additional covertness, since the holographic signal (already LPI) is now distributed in effectively discrete temporal "chips" across a broad range of frequencies. In the exemplary embodiment, multiple

(n) hops per second are used (hop period = 1/n sec.), with R discrete hop bands of S MHz each (which may be contiguous or non-contiguous within the frequency spectrum), although other values may be used. For example, values of 1000, 100, and 1 might be used for n, R, and S, respectively, although other values (including those in the "slow" FH domain) may be used if desired. In the exemplary embodiment, S is chosen to encompass the entire non-hopped holographic signal bandwidth. Any number of different hopping algorithms may be used consistent with the present invention, the creation and use of which are well known in the communications arts and accordingly not described further herein.

It will be further recognized that other types of frequency hopping may be used consistent with the invention, including for example so-called " adaptive frequency hopping" (AFH). AFH is a method for avoidance of fixed frequency interferers. AFH techniques as used in the present invention might comprise three (3) primary components; i.e., (i) Channel Classification - detecting an interfering source on a channel-by-channel basis; (ii) Hop Sequence Modification - avoiding the interferer by selectively reducing the number of hopping channels or altering the sequence; and (iii) Channel Maintenance – periodically re-evaluating the channels. Channel classification involves the detection of the interfering network. There are various methods to accomplish this, such as for example RSSI measurements, number of consecutive packet errors, packet error averages, etc. Regardless of the classification technique, metrics of channel quality are stored, such as on a channel-by-channel basis. These metrics are then used to classify each channel (e.g., as being either acceptable or non-acceptable, or according to some other non-fuzzy or fuzzy rating scale or scoring algorithm). Once the new pool of good channels has been determined, each device modifies its "hopset" in order to avoid unacceptably noisy or interfering channels. This modification of the hopping set (e.g., via its seed) is synchronized (in time and frequency) between any devices wishing to carry on communications. The foregoing process of channel classification and modification may be performed periodically (channel maintenance), such as at prescribed intervals, or upon the occurrence of one or more events, such as encountering an increased density of "noisy" channels, etc.

As shown in Fig. 1a, the basic transmitted holographic waveform 100 has the appearance of wideband Gaussian noise. As a holographic signal, the information contained within it lies mainly in the zero-crossings 102 of the signal. Another enhancement provided by the present invention comprises clipping (or enveloping) the output waveform before transmission, and

converting it into random, binary signals 104 of plus and minus pulses of equal amplitude, but with random duration 106 (see Fig. 1b). Advantageously, the zero-crossings 102 are left intact. In this form, the transmission can be mixed with other non-covert digital transmissions if desired to hide it or even disrupt those other transmissions.

Referring now to Figs. 2a and 2b, yet another improvement provided by the present invention is described. Specifically, in the illustrated embodiment of Fig. 2b, a waveform containing "sharp" (short temporal duration, e.g. 10 ns, 1 ns, 0.1 ns), high-bandwidth pulses 210 of uniform amplitude occurring at the zero-crossings 202 of the original output waveform is used. This approach increases the spread bandwidth. This signal, when received, can be reconstituted as a binary holographic signal from which the base band can be retrieved. These sharp pulses 210 are not on the base band signal, but rather on the holographic transmitted waveform. This approach uses the sharp pulse feature somewhat comparable to current "ultra-wide-band" (UWB) technology, but in the context of the holographic waveform. It will also be appreciated that while "sharp" pulses are described in the illustrated embodiment, other pulse shapes may be used consistent with the invention. For example, short duration Gaussian pulses may be utilized, as well as other pulse waveforms. The pulse amplitude may be varied or modulated as desired also.

It will further be recognized that the foregoing techniques can be used in isolation or jointly as desired. For example, a FHSS system employing waveform clipping/enveloping as described above may be made. Alternatively, a "sharp" pulsed FHSS system may be used.

The techniques can be temporally intermixed as well, such as by utilizing "sharp" pulses for a period of time, then clipped/enveloped pulses, etc. The "hopping" between (and duration of each instantiation of) these different pulse forms can be controlled by a second (and even third) pseudo-random algorithm akin to that utilized for the spectral access spreading described above, in order to randomize the transitions and duration of each interval. In this fashion, synchronization between transmitter and receiver is no more difficult than that for the FHSS approach. Hence, a triple-domain hopping approach is contemplated, wherein (i) the carrier frequency is hopped as previously described (first domain); (ii) the pulse modulation type is hopped between two or more alternatives (second domain); and (iii) the temporal duration of each modulation type is hopped (third domain). Convolutional coding of the type well known in CDMA systems can also be optionally employed if desired to reduce BER on pulse modulation

transitions (i.e., where one or more bits of data may be lost on the transmitter/receiver shifting from one modulation scheme to the other); by moving these "lost" bits around in the transmitted data stream, their effect will be inconsequential.

When coupled with the intrinsically noise-like signals by the basic holographic technique, this in effect produces an unintelligible "soup" of communications signals to any potential interceptor. Only explicit knowledge of all three hop algorithms (and the convolutional code) will allow detection and decoding. Since the hop sequences are all effectively randomized, the radiated energy appears substantially "white" as well.

The foregoing is merely exemplary; numerous different permutations of these features of the invention are possible, such combinations being readily implemented by those of ordinary skill in the wireless spread spectrum communications arts given the present disclosure.

Adding Multiple Users and Pages Simultaneously

The process of having multiple narrow-band users communicate simultaneously within a spread spectrum bandwidth is a major feature of modern cellular technology such as CDMA (Code Division Multiple Access). Each user effectively produces a direct sequence waveform, with a different pn code being assigned for each user. The codes are at least substantially orthogonal, thereby providing (i) so-called "graceful degradation" as the channel capacity is reached, and (ii) for easy separation of users from one another when operating at less than capacity.

In another exemplary embodiment of the present invention (Figs. 3a and 3b), a group of users of the communication system (which may comprise all or a subset of the total number of users of the system) are provided the same scrambling code, but different frequency offsets so that the narrow base-band spectrums of all the users are at least substantially orthogonal (non-overlapping). These offsets may comprise a predetermined set of frequencies (large enough to separate the base bands of the individual users, e.g. 10 kHz separations for voice, 10 MHz separations for video, etc.), or may be made deterministic on one or more other parameters (such as the selected "center" frequency, etc.). This approach is advantageously more efficient on the use of available spread band width, limited available codes, and further avoids problems of "friendly code jamming", i.e., when all users are communicating simultaneously. In other words, the spread signals of those users with which a given user is not communicating do not act as noise for the one user with which the given user is communicating. This is in contrast to

traditional DSSS/CDMA systems, wherein greater channel utilization does induce some degree of degradation in signal quality. In addition, this approach advantageously maintains constant processing gain for each additional user as for a single user transmitting alone.

The foregoing principles are illustrated in the exemplary configuration of Figs. 3a and 3b (transmitter and receiver, respectively) for 10 simultaneous users, although it will be recognized that more or less users may exist consistent with the invention. As shown in Fig. 3a, the transmission process 300 generally comprises first encoding the user's message data using the same spreading code 302, then assigning a frequency offset to each 304. Specifically, when a user transmits a signal, a single modulator simultaneously converts the signal into a modulated signal using a common phase code q(t) and a respective frequency offset (F_1, F_2, ...F_N). In one embodiment, bi-phase shift keying (BPSK) modulation is used. It will be recognized that other digital modulator techniques may also be used, including but not limited to other phase shift keying (PSK) techniques, amplitude shift keying (ASK), frequency shift keying, continuous phase modulation (CPM), and "hybrids". Other PSK techniques include but are limited to quadrature phase shift keying (QPSK), π/4-shifted QPSK, and differential quadrature phase shift keying (DQPSK). ASK techniques include but are not limited to quadrature amplitude modulation (QAM) and n-state quadrature amplitude modulation (nQAM, where n may equal different number of constellation values such as 64). CPM techniques include but are not limited to minimum shift keying (MSK) and Gaussian minimum shift keying (GMSK). Hybrid modulation techniques include but are not limited to vestigial side band (VSB). Likewise, quadrature phase shift keying (QPSK) can also be used to combine the real and imaginary parts of the complex holographic signal into one real signal for transmission over the air channel.

The signals of varying frequency offset are then fast fourier transformed (FFT) 306, although other transformation techniques may be used (such as the Cosine transform described in greater detail subsequently herein). If digital-to-analog conversion is necessary, the signal will then be converted using a software or hardware DAC (not shown). The signal is then transmitted using a transmitter 308, with FHSS spreading as previously described applied if desired. In the illustrated embodiment, a radio-frequency transmitter is utilized. However, as described below in greater detail, other transmitters may be used including, but not limited to, microwave (radar), sonar, and matter wave transmitters.

Once transmitted, the receiver (Fig. 3b) receives the signal and the signal is converted from analog to digital using an analog-digital converter (A/D converter) if necessary. Hardware, firmware, or software, or any combination thereof, are used to inverse fast fourier transform (FFT^{-1}) the signal 316. The receiver system despreads the signal before determining the intended user target by selecting the user's offset frequency. The signal is then low pass filtered and demodulated to extract the carrier from the data. As shown in Fig. 3b, all users have their transmissions simultaneously "de-spread" by one code, and low pass filters 320 in the receiver isolate each user from the others. Additional processing units in the receiver can allow the simultaneous reception of all users.

Although the assignment of different frequency bands for actual transmission (e.g., FDMA) is a known broadcast and communications technology, it has always been applied in the prior art to the actual transmitted waveforms. In the holographic technology of the present embodiment, however, the offset frequency bands are assigned in the base-band signal. The transmitted holographic waveform still comprises the same spread (and hopped, if desired) band as in prior embodiments; the aforementioned offset bands do not appear in the transmissions, thereby increasing the covertness of the transmissions. Accordingly, this embodiment of the communication system is well suited for military special operations forces and other small group communications (e.g., flights of related aircraft) where a limited number of users require highly covert communications.

It will also be recognized that the Fourier transforms used in conjunction with the invention can be performed on blocks of a fixed or variable size. For example, in one embodiment, a power of 2 is used as the basis for the transform. Alternatively, another embodiment varies the block size according to a variation scheme. One exemplary variation scheme comprises in effect randomizing the block size via a pseudo-noise (pn) or other pseudo-randomized/randomized code. This latter approach advantageously increases the covertness and resistance to eavesdropping of the invention, since the constantly changing block size (i) further eliminates any "beats" or other easily-identified patterns within the holographic signal; and (ii) randomizes the FT parameters such that even if one knows that a Fourier transform is being used to construct the signal, they will have extreme difficulty obtaining any useful information from the inverse-transformed signal due to the unpredictable transform parameters used within the transmitter. The block size can be modulated according to a pattern as well (e.g., block size "X"

is a data "0", and block size "Y" is a data "one" in a simple example), thereby in effect coding information therein. Such technique may be useful, for example, in training a receiver for subsequent reception; i.e., transmitting a data sequence via the block size modulation which uniquely identifies one of a plurality of available pn sequences to be used by both receiver and transmitter in varying block size as previously described, or which is used as a seed for a hopping algorithm.

Additionally, the offset frequencies assigned to multiple users need not be a fixed collection, but can be changed on a frame-by-frame basis if desired according to a pre-determined code pattern such as those previously described. This technique advantageously further randomizes the transmitted signals and minimizes the production of recognizable beats in the transmitted holographic signals. It also permits better identification of the individual users in the receiver in the presence of unknown delays between transmitter and receiver caused by signal transit time and the presence of multi-path signals. For example, were a fixed set of offsets assigned to a plurality of users, the presence of multiple propagation paths could potentially result in degradation of the signal associated with one or more users. In contrast, by varying the frequency offset assigned to those users, the effect of a given set of multi-path signals would vary as a function of the offset frequency, thereby limiting the period during which that particular effect would occur. Stated differently, each new offset can produce at least some variation in multi-path environment.

In yet another embodiment, offset frequencies are assigned to each user of the same scrambling code, in the ratios of prime numbers (i.e., those which are only divisible by themselves and one). This technique helps minimize any recognizable beat patterns in the transmitted waveforms. Similarly, other "low observable" offset assignment schemes may be utilized, such as random or pseudo-random assignment via a seeded algorithm as described above with respect to spectral hopping band assignment (FHSS), or yet other well known approaches. As yet another alternative, an adaptive approach can be used, wherein frequency offset assignments are made according to evaluations of channel noise, interference, jamming or the like.

It will be further recognized that the aforementioned feature of assigning the same scrambling code to multiple users, and using offset frequencies to separate them at the receiver, can also be adapted to effect high bandwidth communications of large amounts of data by a few

or one user. In one exemplary embodiment (Figs. 4a and 4b), the information is represented by a plurality of "frames" or packets of waveform data being transmitted simultaneously. Each frame has the same scrambling code but a different offset frequency. In one exemplary transmission-processing scheme, all of the different frames are added together to form a single composite "super frame" before the Fourier Transform operation (FFT) 406 of Fig. 4a is conducted.

In yet another embodiment, a multitude of users, each with a multitude of frames of data, use the same scrambling codes, but offset frequencies different for each user and different for each of the information frames are provided. Once again, all the offset frequencies are chosen to eliminate beat or otherwise recognizable patterns in the transmitted signals (through, e.g., use of prime numbers or other comparable mechanisms previously described herein).

The foregoing approach may also be applied dynamically by the system. For example, where communication between multiple (sets of) users is required, each user can be allocated a frequency offset. However, where one or more users wish to transmit larger amounts of data, available frequency offsets can in effect be traded for bandwidth, with one or more users having multiple offsets assigned to them. Such users can then continue voice communications if desired, as well as using other assigned offsets for data transmission, up to the available communications bandwidth of the system.

Such "data page offset" approach may also be employed for "bursty" communications, for example where the user wishes to transmit a large amount of information in a short period of time. This feature may be useful to maintain covertness (i.e., shorter temporal duration of transmission generally equates to greater reduction in probability of intercept), or to maintain continuity of communications with respect to geographic or structural hazards such as large buildings or tunnels.

It is to be recognized that in all of the above described frequency offset techniques for both multiple users and multiple pages of data per user, processing gain remains the same as for a single user and is determined solely by the ratio of total spread band width to the band width of a single page of data. It is also to be recognized that the data rate for each page of data and user can be different and in fact dynamically changed from frame to frame.

Defeating Interceptors by Time Dithering

The transmitted holographic waveforms associated with the exemplary embodiment of the '480 Patent solution generally have the appearance of wide-band, zero-mean, stationary

Gaussian noise. They appear to be natural background or thermal noise. There is very little content contained in these waveforms that an interceptor of the signal can recognize as human made other than finite power. However, the '480 Patent solution does in one embodiment make use of signals sampled at a definite or predictable chip-clock rate. A determined and sophisticated interceptor might make use of correlation receivers of the type known in the communications arts that seek to identify a chip-clock signature within a spread spectrum, thereby detecting the presence of the transmission with high reliability (albeit perhaps not the content of what is being transmitted). In many situations (such as for example the search and rescue of downed aviators during wartime, or the operations of special forces), even the detection of communications aside from their content can provide a basis for hostile forces to locate the transmitter, or at least be alerted to its presence.

For a more covert or stealthy holographic signal, one exemplary embodiment of the present invention dithers the epoch of the chip clock by, e.g., a fraction of the base chip rate (or some other parameter). This dithering procedure can significantly reduce the efficiency of a correlation receiver in detecting the presence of the holographic signal, in effect taking away the regular or predictable "man-made" component of the transmitted signal. The dithering of the chip rate can be made totally deterministic if desired, and dependent upon sequences of random or pseudo-random numbers known to both transmitter and receiver of the holographic signals (such as by using the aforementioned pseudo-random algorithms). In another embodiment, the sequence can be derived from the base scrambling codes previously described, so that only one code sequence need be used. The receiver then "un-dithers" the received signal, and recovers the base-band messages with higher fidelity.

Use of Real Data and Real Transforms

Complex waveforms (two components, real and imaginary) generally require specifically adapted hardware and software, thereby increasing the cost and complexity of any holographic solution. Accordingly, in one exemplary embodiment of the invention all "real" signals (i.e., having no complex or imaginary component) are used. This is advantageously less expensive and less complex in hardware and software implementation.

Fourier Transforms (FFTs) represent one time domain-to-frequency domain conversion technology useful with the present invention, although other kinds of transformations that also

preserve the convolution feature of the FFT may be used. Some of these other transformations can be used entirely in the real data domain, such as the Cosine transformation. The Cosine transformation not only takes a real input, but also produces a real output waveform for transmission. It is generally faster than the Fourier Transform, and cheaper to implement in hardware/software. However, as is well known, the Fourier transform can also be used to transform two real signals simultaneously if necessary. For example, the enhanced FFT processing methods and apparatus disclosed in pending United States Patent Application No. 20020194236A1 to Morris published December 19, 2002 and entitled "Data processor with enhanced instruction execution and method", which is incorporated herein by reference in its entirety, allow even an embedded RISC device to perform the required FFT operations at high speed.

One exemplary phase code modulator embodiment described in the '480 Patent produces complex base-band signals by incorporating all angles from $-\pi$ to $+\pi$. However, by operating the modulator with just two angles, 0 and π, chosen randomly, the resulting phase codes are real consisting of 1s and −1s (see Fig. 5). The phase code modulator 500 then operates in effect as a "direct sequencer". Specifically, if the DC reference signal is removed, and only the PSK signal retained, an all-real base-band signal is produced for the transformer operation, comparable to a direct sequencer. The tradeoff in implementing this approach is the loss of the DC spectrum spike used in the exemplary '480 Patent receiver to locate frequency-offset signals after code de-spreading. Accordingly, in one exemplary embodiment, the receiver of the present invention is configured to locate the spectral peaks of Sin(x)/x type distributions. This is accomplished via a software algorithm running on the processor (e.g., DSP) of the receiver, although other approaches (including custom ASICs or hardware logic) adapted to determine the spectral peaks may be used. Such peak-detecting algorithms are well known in the signal processing arts, and accordingly not described further herein.

Doubling Data Rates

In yet another embodiment of the invention, an improved method of referencing is utilized. Specifically, the use of one input channel as a reference signal (used to encode a constant value signal that produces a sharp frequency spectrum spike that is easy to recognize, as shown in Fig. 6a) is obviated in favor of an improved technique whereby the data rate of the

communications is significantly increased (e.g., effectively doubled in a two-channel system). In the exemplary embodiment, the former reference channel is used for actual PSK type data, similar to the other non-reference channel(s). Rather than generating a spectrum spike for the receiver to locate, a broader Sin(x)/x or comparable type distribution is generated, from which the location of the peak can be made as accurately as from the original "spike" spectrum (see Fig. 6b). Hence, enhanced data throughput is achieved with no reduction in system operation or signal quality.

Measuring Distances from the Delayed Holographic Signal

Delay present in the received holographic signal is primarily due to the finite transit time T of the holographic signal from the transmitter to the receiver. Thus, if T is measured to be 500 ns, the distance from transmitter to receiver is approximately 500 feet (for an electromagnetic wave propagating at approximately 3E08 m/s). Spectral estimation methods well known in the art allow measurement of the frequency offset of the base-band signal in the receiver to an accuracy that permits determination of T, with an error on the order of 50 ns or less. A theorem of Fourier analysis directly relates the time shift (delay) in the holographic signal to its de-spread spectral offset frequency. Accordingly, the present invention provides ability to use the received signal to estimate the distance to the transmitter. With two separated receivers, the transmitter can be located by well known triangulation means.

Correcting Multipath Distortion

In another aspect of the invention, methods for correcting for multi-path distortion are provided. Fig. 7 illustrates one embodiment of the method 700, wherein filtration is used to isolate and remove the time-delayed multi-path signal. Advantageously, after the inverse Fourier transformation in the receiver, the multi-path signals are all in time registration, but have frequency offsets characteristic of their time delays in the air channel transit. This is a known property of the Fourier transform algorithm. An additional benefit of the invention is that all the multi-path signals can be simultaneously de-spread by a single code (inverse of original scrambling phase code). A spectral display shows the individual power spectrums of each multi-path signal. Spectrums that do not overlap can be removed by filtering. When the multi-path delays are small and numerous, the aforementioned spectral bands overlap and cannot be

separated by simple filtering. The overlapping bands produce a reconstructed base-band interference that appears as signal fading. The disadvantage of current wireless technology is that multi-path signals not only interfere with one another in the above-described fashion, but are not registered in time as well. This makes the multi-path fading more severe than for the holographic technology. The invention's method to correct this is to change the transmission frequencies or simultaneously transmit base band messages at multiple frequencies or frequency bands (multiplexing). Another solution that can be implemented is to use convolutional encoding alone or in conjunction with frequency shifting or frequency multiplexing to correct the errors introduced by the multi-path fading.

Miniature Holographic Technology

Today's high speed (multi Gflops processing speed), low power consumption, digital processors and SoC technology allow an entire holographic transmitter and receiver to be integrated and constructed in a very small form factor. Provided herein are exemplary embodiments of such miniaturized technology employing some or all of the foregoing improvements therein, although it will be recognized that myriad other types and configurations may be used consistent with the present invention.

Referring now to Fig. 8, one exemplary embodiment of a miniature transmitter/receiver is disclosed. The form factor of the illustrated device 800 is approximately 3 inches by 3 inches by 1/4 inch, including batteries 802, memory 804, antenna 806, display 808, etc. The device 800 comprises a miniature holographic communication system, including optional keypad or capacitive "touch" screen 810, that can be worn by individuals and easily attached to equipment and vehicles and used for dog tags, identification, always-ready secure and covert communications, search and rescue radios, and "identify, friend or foe" (IFF) communication devices. Such devices would be especially useful in anti-terrorist activities and drug smuggling interdiction, where the target terrorists or drug smugglers frequently possess communications intercept equipment or other means capable of "tipping them off" to the presence or approach of military or law enforcement personnel.

The various holographic communications are performed on a fully integrated low-voltage "system on a chip" (SoC) application specific integrated circuit (ASIC) of the type generally known in the semiconductor fabrication arts (not shown). The SoC ASIC incorporates, *inter alia*, a digital processor core, embedded program and data random access memories, radio

frequency (RF) transceiver circuitry, modulator, analog-to-digital converter (ADC), and analog interface circuitry.

Additionally, the core (and in fact the entire SoC device) optionally includes one or more processor "sleep" modes of the type well known in the digital processor arts, which allow portions of the core and/or peripherals to be shut down during periods of non-operation in order to further conserve power within the device.

The miniature transceiver 800 may also contain a miniature GPS receiver 812 of the type well known in the art (which may be configured in silicon), and be configured to include precise location data with covert transmission of messages or data. Alert messages (such as those asking the user to perform a specific action, or alerting them to the presence of nearby hostile forces) can be sent to a built-in "pager" receiver disposed within the device 800 from other assets such as satellites, overhead aircraft, nearby ships, etc. The device's memory may also contain preformatted messages (e.g., "Downed Aviator" or "Medevac" with attached location data, "Airstrike Request" with desired strike location(s), "Overhead Asset" tasking request with desired location(s), etc.) so that the operator need merely push an appropriate button to instigate the transmission. Such preformatted messages may also be stored in holographic form for immediate transmission.

Use of Other Carriers of Information

In general, the holographic technology of the present invention can be applied to any type of energy wave or beam that can be modulated to carry information.

For example, in addition to radio frequency (RF) electromagnetic energy, the present invention may be readily adapted to "acoustic" energy (e.g., pressure waves formed within a medium of propagation), such as for example sonar and other underwater sound sources. Such acoustic waves can be made noise-like with the present holographic technology, and therefore significantly more difficult to detect and acquire. Specific applications for such acoustic variants of the invention include military uses such as submarine sonar technology (e.g., on the active sonar array), sonobuoys, torpedoes (e.g., Mk-48 ADCAP or similar), air-dropped homing torpedoes, underwater or floating mines, and underwater communications (such as ship-to-ship covert communications systems), where the noise-modulated waveforms would be difficult to hear, recognize, and detect. Additionally, other types of sonar systems, such as those adapted for ocean contour mapping, depth detection, current profiling, marine life detection (e.g., so-called

"fish finders"), or even high-frequency proximity detection sonar used for docking evolutions can utilize the present technology. For example, the Acoustic Doppler Current Profiling (ADCP) systems offered by Rowe-Deines Instruments, Inc. (RD Instruments) of San Diego, CA can be readily modified to include LPI signal processing according to the present invention, thereby providing an excellent LPI current profiler for use on, e.g., military submarines.

Furthermore, the parent acoustic system may comprise any number of transducer configurations, including for example a phased array, spherical array, wide-aperture array (WAA), towed array, etc.

Additionally, the present invention teaches the use of acoustic "overlays" in order to further tailor the radiated acoustic signature or local acoustic environment. Such overlays may comprise, for example, the addition of masking or deception signals that are contemporaneously transmitted with the communications signals. These overlays may either (i) increase the ambient or background noise level within which the LPI communications signal propagates, and/or (ii) provide distractive or deceptive signals intended to cause any listening entity to consider alternative sources or reasons for the LPI signals.

As an example of the first use, a low intensity broadband (e.g., wide spectrum) signal may be radiated contemporaneously or otherwise incorporated into the LPI signals, thereby increasing the background ocean "din". Care must be utilized in this approach, however, to avoid creating what appears as an acoustic "bright spot" on the listening entity's broadband sensors (e.g., submarine sonar "DIMUS" trace), in effect an acoustic marker which stands out over noise emanating from other azimuth/elevation coordinates.

As an example of the second use, natural sea sounds such as whale songs, dolphin chatter, or shrimp snapping (so called "biologics") can be replicated and transmitted with the LPI signals in order to attempt to deceive any listener into believing (or at minimum, analyzing) that the source of the detected acoustic energy is natural in origin. Such biologic sounds can also perform the function of (i) above; i.e., their energy to some degree can mask the LPI signals due to increased background or ambient acoustic levels (db).

Furthermore, the deceptive overlays need not be limited to biologics. For example, a submarine or ship of one nationality may radiate broadband and/or narrowband noise signatures characteristic of another nationality or class of submarine or ship, in order to deceive the listening entity as to the true identity of the vessel. Since most if not all submarine/surface ship

classification systems operate on acoustic signature (e.g., broadband signature, narrowband "tonals", propulsion blade rate, transients, etc.), they can be fooled by a very silent platform having a first signature profile but radiating a second, more salient deceptive signature. For example, where the listeners are expecting to hear or detect a submarine having a particular signature, and there is a probability that the LPI signals may be detected if not "masked", it may be desirable to emit the deceptive acoustic signature contemporaneously with the LPI signals, since it is highly unlikely that the listeners would analyze for LPI signals within the acoustic signature of an ostensibly friendly vessel.

In yet another aspect of the invention, the holographic techniques described herein may be applied to the modulation of microwaves (such as those used in radar) or so-called "millimeter waves" used in data transmission links for the purpose of creating noise-like signals that cannot be detected by interceptor technology. In the context of radar, the utility of such covert emission is self-evident. For example, since many military platforms utilize signals detection equipment to detect RF/electromagnetic signals and assess the nature of the threat (so-called "ELINT" and "SIGINT"), the ability to scan or interrogate in a substantially passive manner provides a huge tactical advantage.

Consider, for example, the foregoing submarine operating in coastal waters. Many defensive or military installations (or their patrolling surface vessels) use surface-search radars to scan for approaching ships, small boats, or other anomalies (such as submarine periscopes). Current state-of the art radars (including synthetic aperture radar or SAR, discussed below) can detect exceedingly small artifacts, including for example birds, small surface waves, etc. Yet all such prior art systems suffer from an active radiated energy profile; i.e., if the vessel creating the artifact (e.g., submarine) is properly equipped, it can detect the electronic signature of the coastal radar and mitigate its radar cross-section (RCS), such as by immediately lowering its sensors/periscope. Hence, under the prior art, the submarine enjoys the advantage of a "hit and run" RCS (i.e., a small RCS existing for only a very short period of time), thereby limiting its chances of being detected.

However, were the utility of the submarine's ELINT/SIGINT sensors defeated through the use of an undetectable (or at least LPI) radar system, the submarine may be provided with a false sense of security, thereby perhaps keeping its sensors/periscope in an exposed posture for a longer period of time. Since these sensors, typically housed in an extending mast, cannot be

made completely "stealthy" (i.e., the RCS can never be completely eliminated) to a degree to defeat SAR and other comparable radars, the LPI radar system of the present invention would alter the balance of tactical advantage in such situations from the submarine to the scanning radar.

Other uses for the LPI radar of the present invention are also readily envisaged. For example, low-observable (stealth) aircraft such as the F-117 Nighthawk, F-22 Raptor and B-2 Spirit often severely limit "active" RF emissions during operations in order to maintain their covertness. This is particularly true of navigation and detection sensors; rather than use an active RF radar, passive systems such as a FLIR are substituted. However, in certain circumstances, it would be desirable to have a radar system (especially for long-range threat detection) if covertness could be maintained. The LPI radar system of the present invention affords such capabilities, since it effectively eliminates any traditional radar energy signature. Similarly, the aforementioned submarines or surface ships (e.g., SPY-1 A/D variants of Aegis phased array weapons system used in the latter) could be given a "passive" radar capability, something lacking in current submarine and naval radar technology.

In one exemplary embodiment, the holographic technology of the present invention is adapted to a Doppler-based radar system having an antenna/aperture, transmitter block, receiver block, signal converter (e.g., ADC, as required), and signal processing block. The holographic signal processing described previously herein may be performed in software, firmware, or hardware, or any combinations thereof. In one embodiment, the holographic processing (including Fourier or Cosine transforms, etc.) is performed within the signal processor(s) (e.g., DSPs) of the signal processing block, along with the Doppler processing. In the case of Fourier transforms, his is accomplished using FFT signal processing algorithms of the type well known in the art. This approach advantageously requires a minimum of modification to existing systems, thereby enhancing retrofit capabilities.

It will further be recognized that the present invention may be utilized in both pulsed and CW (continuous wave) systems if desired, the adaptation to each such system being readily accomplished given the present disclosure.

The present invention may also conceivably be adapted to SAR systems as well, such as for example the AN/APY-8 Lynx™ SAR manufactured by General Atomics Corporation of San Diego, CA. Synthetic Aperture Radar (SAR) refers to a technique used to synthesize a very long

antenna by combining signals (echoes) received by the radar antenna as it moves along its flight track. The term aperture refers to the opening used to collect the reflected energy that is used to form an image. In the case of radar, the aperture comprises the antenna. A synthetic aperture is constructed by moving a real aperture or antenna through a series of positions along the parent platform's flight track. As the radar moves, one or more RF pulses are transmitted at each position; the return echoes pass through the receiver and are retained in an "echo store." Because the radar is moving relative to the target, the returned echoes are Doppler-shifted. Comparing the Doppler-shifted frequencies to a known or reference frequency allows returned signals to be "focused" on a single point, effectively increasing the length of the antenna that is imaging that particular point. This focusing operation, commonly known as SAR processing, is done digitally and matches the variation in Doppler frequency for each point in the image. This processing requires very precise knowledge of the relative motion between the platform and the imaged objects. However, the LPI signal processing required by the present invention can be readily accommodated in parallel with the SAR processing (e.g., using any number of readily available high-speed digital processors), thereby allowing for parallel aperture synthesis and holographic processing.

LPI radar may also be readily applied to weapons systems, such as those using active radar systems for terminal guidance, to increase their "stealthiness". For example, active air-to-air systems such as the AAMRAAM, HARM, AIM-7 Sparrow, AIM-54C Phoenix, and the like can be readily modified to incorporate LPI holographic radar technology as taught herein. Anti-ship weapons such as the Tomahawk anti-ship missile (TASM) or UGM-84 Harpoon which utilize an active terminal phase seeker can also benefit significantly. Even traditionally passive systems such as the ALCM, Tomahawk (TLAM), or Joint Direct Attack Munition (JDAM) which utilize GPS, topographical contour and/or "scene" matching (e.g., TERCOM, DSMAC) can be adapted to include a "passive" radar system according to the present invention. For example, the passive LPI radar could be used in a confirmatory fashion for mid-course or terminal guidance (e.g., turned on/off in essence gathering periodic "snapshots" for analysis and comparison to GPS/TERCOM/DSMAC data), threat detection and avoidance (e.g., dynamic route alteration based on threats detected after launch but before terminal delivery), "stealth" communications or telemetry between the munition and its parent platform (or other PGMs en route to the same or different target), for secure GPS communications to and from the PGM, etc.

The LPI radar of the present invention could similarly be used to supplement or even replace the TERCOM radio altimeter present on the ALCM/TLAM or similar systems.

Additionally, remotely piloted vehicles (RPVs) such as for example the General Atomics Predator, Gnat, Prowler, and Altus units, or the Teledyne RQ-4 Global Hawk, can be equipped with the holographic radar system of the present invention. This provides such vehicles with enhanced stealth and covertness which current on-board radar systems do not offer.

Anti-ground/airborne weapons deployed on low-orbit space systems such as the Space Shuttle or satellites may also utilize the LPI radar of the present invention for stealthy or passive radar target acquisition or guidance. For example, space-to-air weapons could utilize the LPI system to preclude detection of targeting or terminal guidance radars. Radar-based orbital intelligence satellites (such as the Lacrosse systems) or earth-mapping/resource detection may also benefit from the application of the present invention, in that covert radar mapping or ground penetrating radar scans may be desired by the overhead asset operator.

It will be recognized from the foregoing that myriad different uses for the LPI radar of the present invention may be found, all such uses being readily implemented by those of ordinary skill in the radar arts given the present disclosure.

In the context of millimeter wave or satellite data systems (such as used for long distance point-to-point backbone data transmission in high-speed data networks, or transmission of DSS content signals in a satellite TV network, for example), the present invention may also be used to increase the covertness of these transmissions, thereby increasingly frustrating attempts at surreptitious piracy or modification of the streamed data. The LPI and other features of the invention both reduce the likelihood of detection and the ability to "hack" into the data, thereby enhancing security. Furthermore, data transmitted using the LPI approach of the present invention may be encrypted and protected against corruption, surreptitious or otherwise, such as through use of well known encryption techniques (e.g., public/private keys, DES), or any other of a plethora of well known techniques. The present invention is also compatible with convolutional and other error correction techniques (such as systematic or non-systematic "turbo" codes) that, *inter alia*, enhance the robustness of the communications channel.

In another aspect, the holographic techniques of the invention can be applied to higher frequency electromagnetic radiation (EMR), including visible or non-visible light, gamma rays, and X-rays. Hence, LPI light/gamma/X-ray scanning or communication systems are readily

produced. These EMR sources may be coherent or non-coherent. For example, a laser (coherent) system can use the present technology to produce an LPI light beam for scanning or other tasks, such as a laser rangefinder or target designator ("painter") for, e.g., hand-held anti-armor or anti-aircraft weapons such as TOW, Javelin, or Stinger, battle tanks (such as the M1A2, Bradley, Stryker), aircraft (such as the AH-64Apache Longbow, AC-130 Spectre, etc.) or ships. Integrated combat systems such as the planned Future Combat System, which integrates unmanned ground and aerial vehicles, can also benefit from use of the present invention. These devices would have the advantage of increased stealth and lethality as compared to existing "dirty" or non-LPI systems, thereby providing greater tactical advantage to the parent platform or user.

In yet another aspect of the invention, sub-atomic particle beams (e.g., electron/positron, neutron, proton, and even neutrino) can be modulated according to the holographic techniques previously described. As the use of particle beams and other matter waves become more prevalent, information can be modulated onto them as well, using various modulation schemes such as binary pulse amplitude. Since many of these beams move at speeds that are relativistic, information can be transferred at nearly the same speed as more traditional radio waves. Moreover, many of these particles (such as neutrinos) can penetrate planet-size objects with very low probability of interaction.

Exemplary Wired Applications

Although the previous embodiments of the invention are generally associated with wireless communications systems, the invention's application is not so limited. For example, it will be recognized that wired communication systems including but not limited to, e.g. RF coaxial cable systems, trans-oceanic cables, NAVY SOSUS fiber cable arrays, optical systems, and even standard "POTS" telephony systems can be used as the bearer medium for the holographic signals.

In cable applications (e.g., HFC networks), the invention advantageously facilitates the use of more efficient modulation techniques. For example, currently, 64QAM is used primarily for sending digital data downstream over a coaxial network because of its efficiency in supporting up to 28-mbps peak transfer rates over a single 6-MHz channel. However, its susceptibility to interference currently makes it ill suited for upstream transmissions. The present invention reduces that susceptibility. Likewise, VSB has traditionally been used by hybrid networks for upstream digital transmission because it is faster than the commonly used QPSK. However,

VSB is also more susceptible to noise than QPSK, and so its use has been limited. Again, the invention reduces such susceptibility.

This invention also expands the capabilities of current communications systems without requiring the installation of an entire new system. This is further enhanced by the ability of the invention to utilize baseband modulations of any type including non-digital, analog amplitude and frequency modulations. For example, current telephone modems (e.g. 1200-bit modems) and paging systems use FSK signals. More secure transmission of data over these systems would facilitate expanded use. Furthermore, because holographic communication methods may also be used with amplitude-shift-keyed (ASK) signals, fiber optic systems may also utilize the techniques.

The holographic techniques can also be applied to Internet or other "un-trusted" network transactions in order to increase security, enhance redundancy (via convolution), etc. In addition to the aforementioned millimeter wave systems commonly used in portions of the network backbone, covert holographic communications may be initiated at other points in the network, even as far out on the network as the endpoints (i.e., user terminals). Hence, the present invention can be used to complement or supplant traditional security paradigms such as the Virtual Private Network (VPN), wherein users within a security perimeter may transfer encapsulated packetized data over an un-trusted network in a secure fashion to another security perimeter.

It will be recognized that while certain aspects of the invention are described in terms of a specific sequence of steps of a method, these descriptions are only illustrative of the broader methods of the invention, and may be modified as required by the particular application. Certain steps may be rendered unnecessary or optional under certain circumstances. Additionally, certain steps or functionality may be added to the disclosed embodiments, or the order of performance of two or more steps permuted. All such variations are considered to be encompassed within the invention disclosed and claimed herein.

While the above detailed description has shown, described, and pointed out novel features of the invention as applied to various embodiments, it will be understood that various omissions, substitutions, and changes in the form and details of the device or process illustrated may be made by those skilled in the art without departing from the invention. The foregoing description is of the best mode presently contemplated of carrying out the invention. This description is in no way

meant to be limiting, but rather should be taken as illustrative of the general principles of the invention. The scope of the invention should be determined with reference to the claims.

WHAT IS CLAIMED IS:

1. A method of transmitting data from a plurality of users, comprising:

assigning the same phase code to said users to create first signals;

assigning unique frequency offsets to each of said first signals corresponding to said users to generate offset signals;

Fourier-transforming said offset signals to produce transformed signals; and

transmitting said transformed signals over a physical medium.

ENHANCED HOLOGRAPHIC COMMUNICATIONS APPARATUS AND METHOD

Abstract of the Disclosure

Improved apparatus and methods for utilizing holographic waveforms for a variety of purposes including communication, ranging, and detection. In one exemplary embodiment, the holographic waveforms are transmitted over an RF bearer medium to provide, *inter alia*, highly covert communications, radar systems, and microwave data links. The bearer (i.e., carrier) is optionally frequency-hopped, and various pulse modulation techniques applied in order to further increase communications efficiency and covertness. Methods of providing multiple access and high bandwidth data transmission are also disclosed. Improved apparatus utilizing these features; e.g., a wireless miniature covert transceiver/locator, are also disclosed.

Fig. 1a

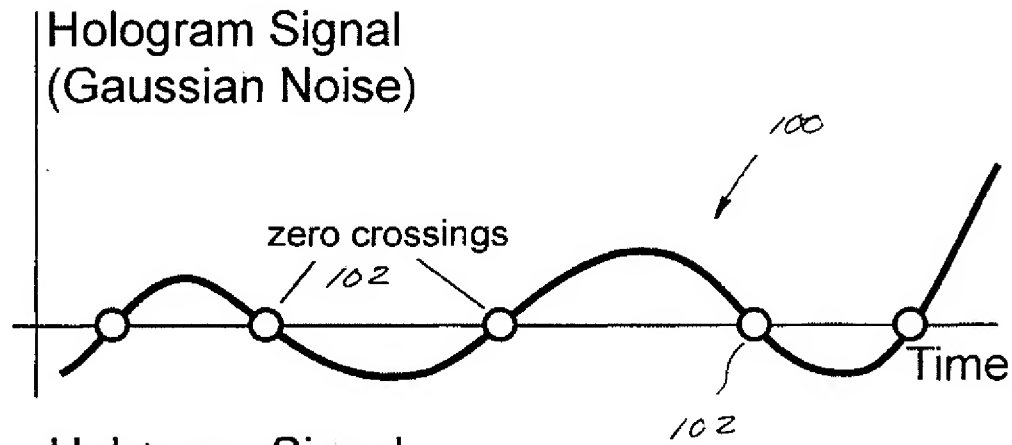

Hologram Signal
(Gaussian Noise)
100
zero crossings
102
102
Time

Fig. 1b

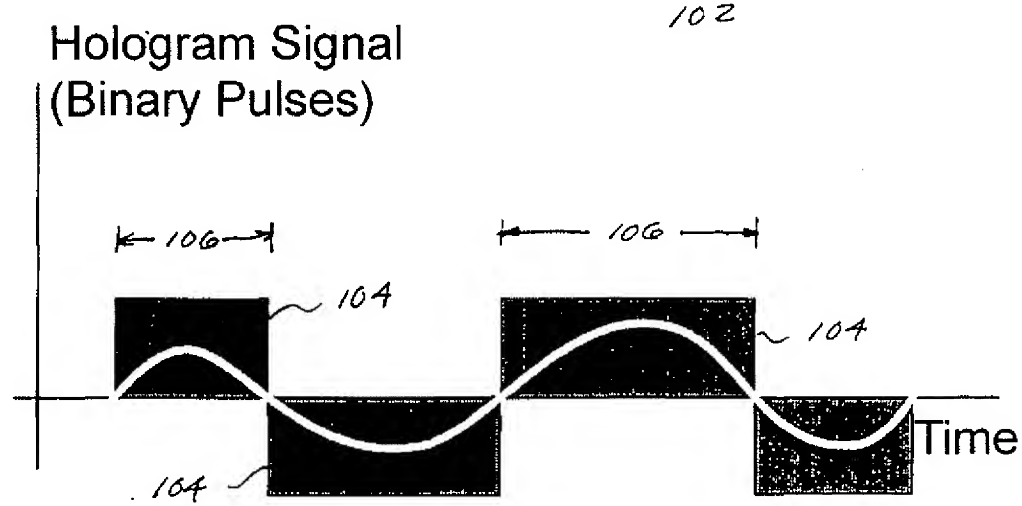

Hologram Signal
(Binary Pulses)
106
106
104
104
104
Time

Fig. 2a

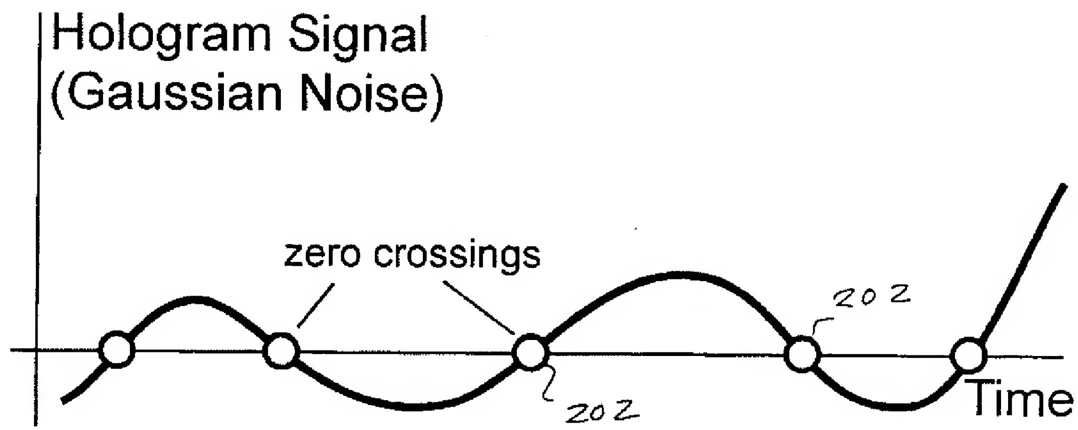
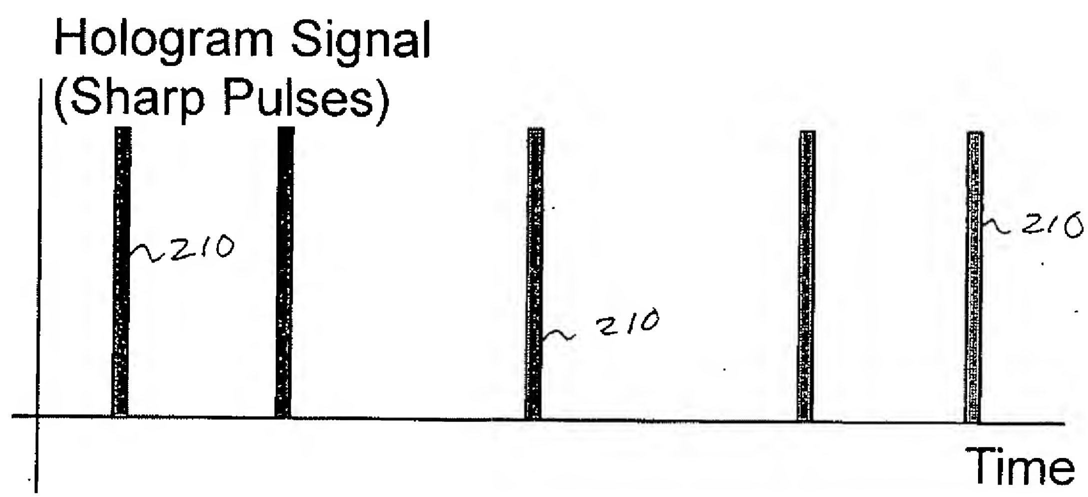

Hologram Signal
(Gaussian Noise)
zero crossings
202
202
Time

Fig. 2b


Hologram Signal
(Sharp Pulses)
210
210
210
Time

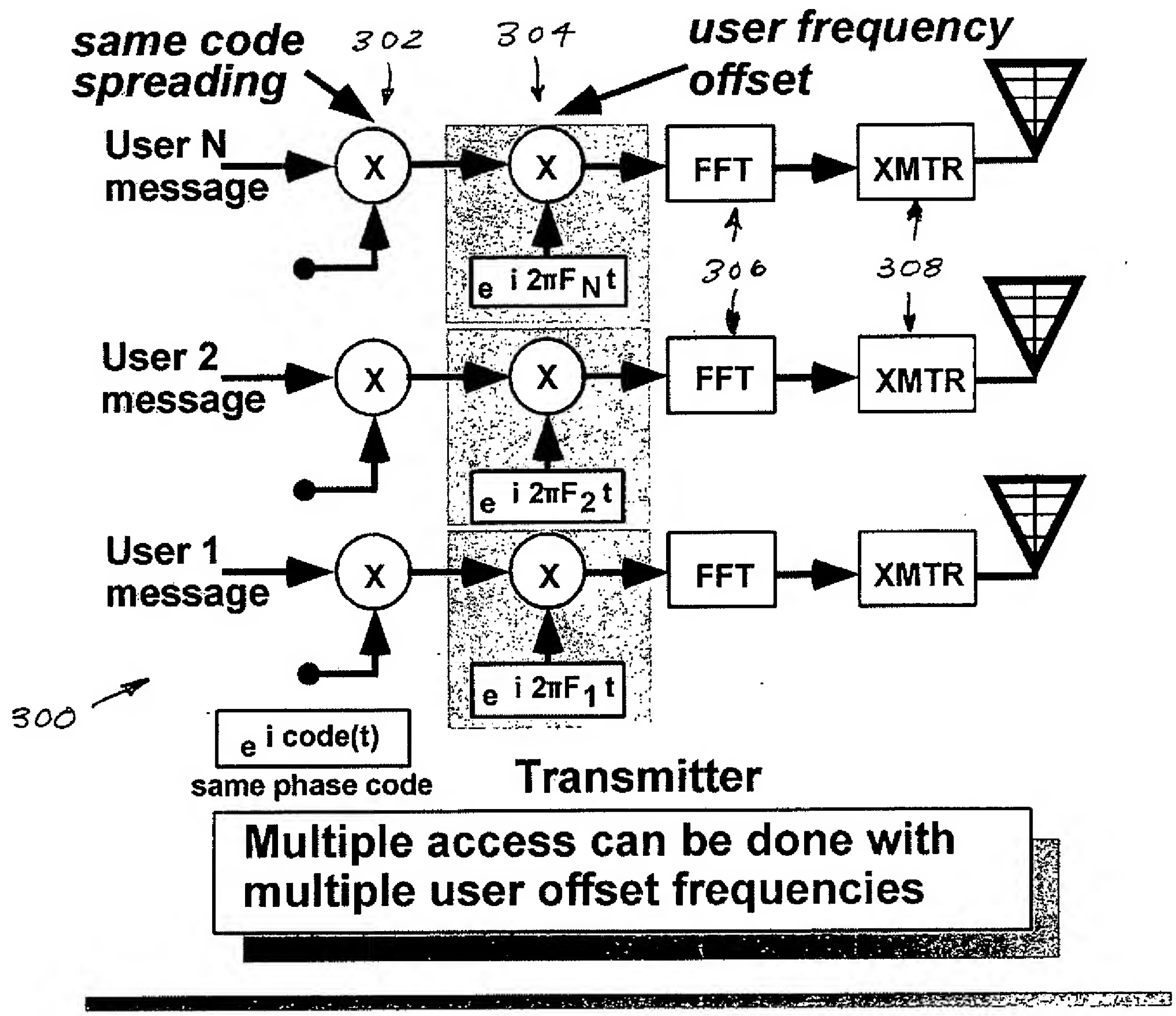

same code spreading
302
304
user frequency offset
User N message
User 2 message
User 1 message
X
FFT
XMTR
306
308
e i 2πF_N t
e i 2πF_2 t
e i 2πF_1 t
300
e i code(t)
same phase code
Transmitter
Multiple access can be done with multiple user offset frequencies

Fig. 3a

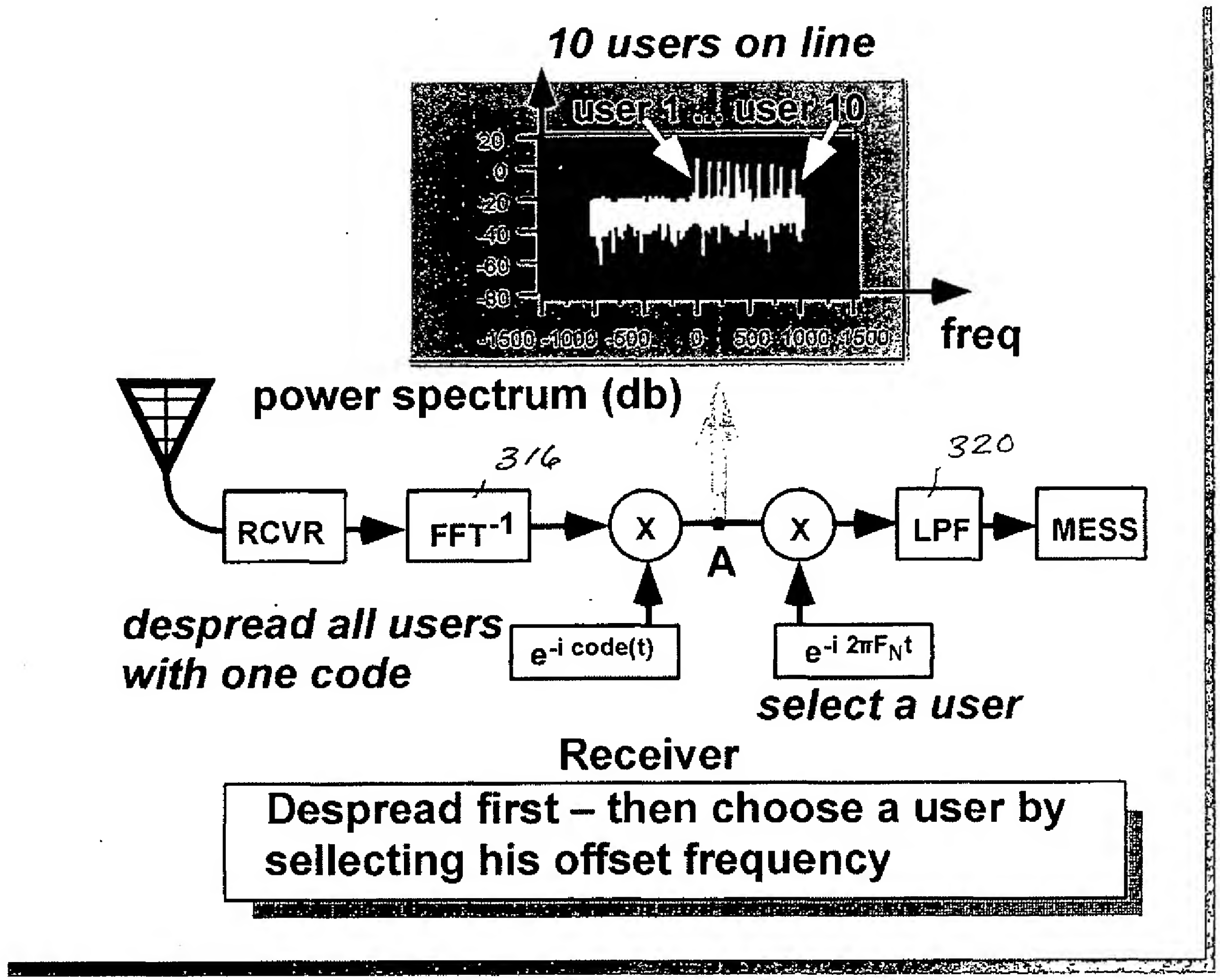

10 users on line
user 1 ... user 10
20
0
-20
-40
-60
-80
-1500 -1000 -500 0 500 1000 1500
freq
power spectrum (db)
316
320
RCVR
FFT^{-1}
X
A
X
LPF
MESS
despread all users
with one code
$e^{-i\ code(t)}$
$e^{-i\ 2\pi F_N t}$
select a user
Receiver
Despread first – then choose a user by
sellecting his offset frequency

Fig. 3b

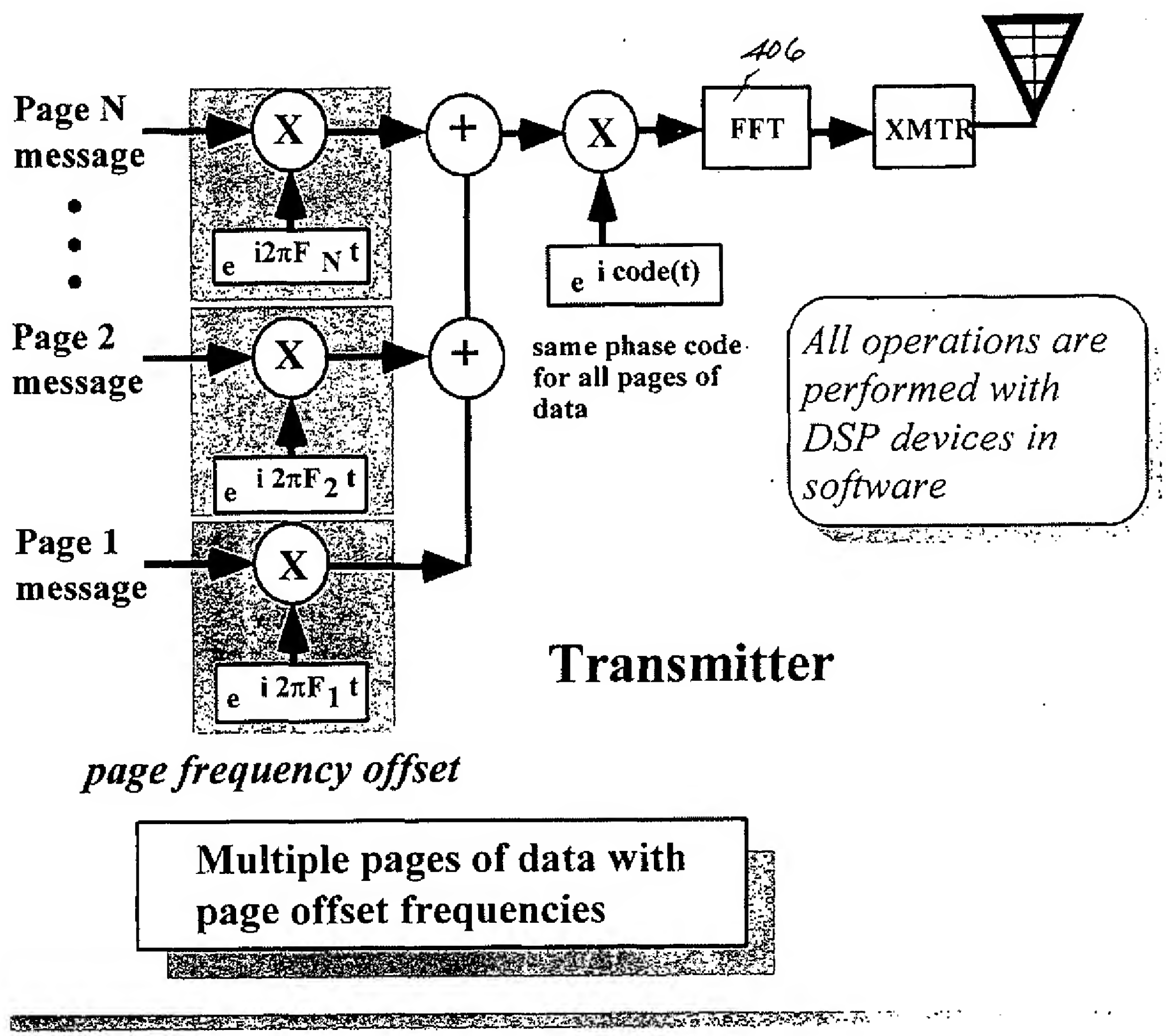

Page N message
Page 2 message
Page 1 message
X
+
$e^{i2\pi F_N t}$
$e^{i2\pi F_2 t}$
$e^{i2\pi F_1 t}$
$e^{i\,code(t)}$
406
FFT
XMTR
same phase code for all pages of data
All operations are performed with DSP devices in software
Transmitter
page frequency offset
Multiple pages of data with page offset frequencies

Fig. 4a

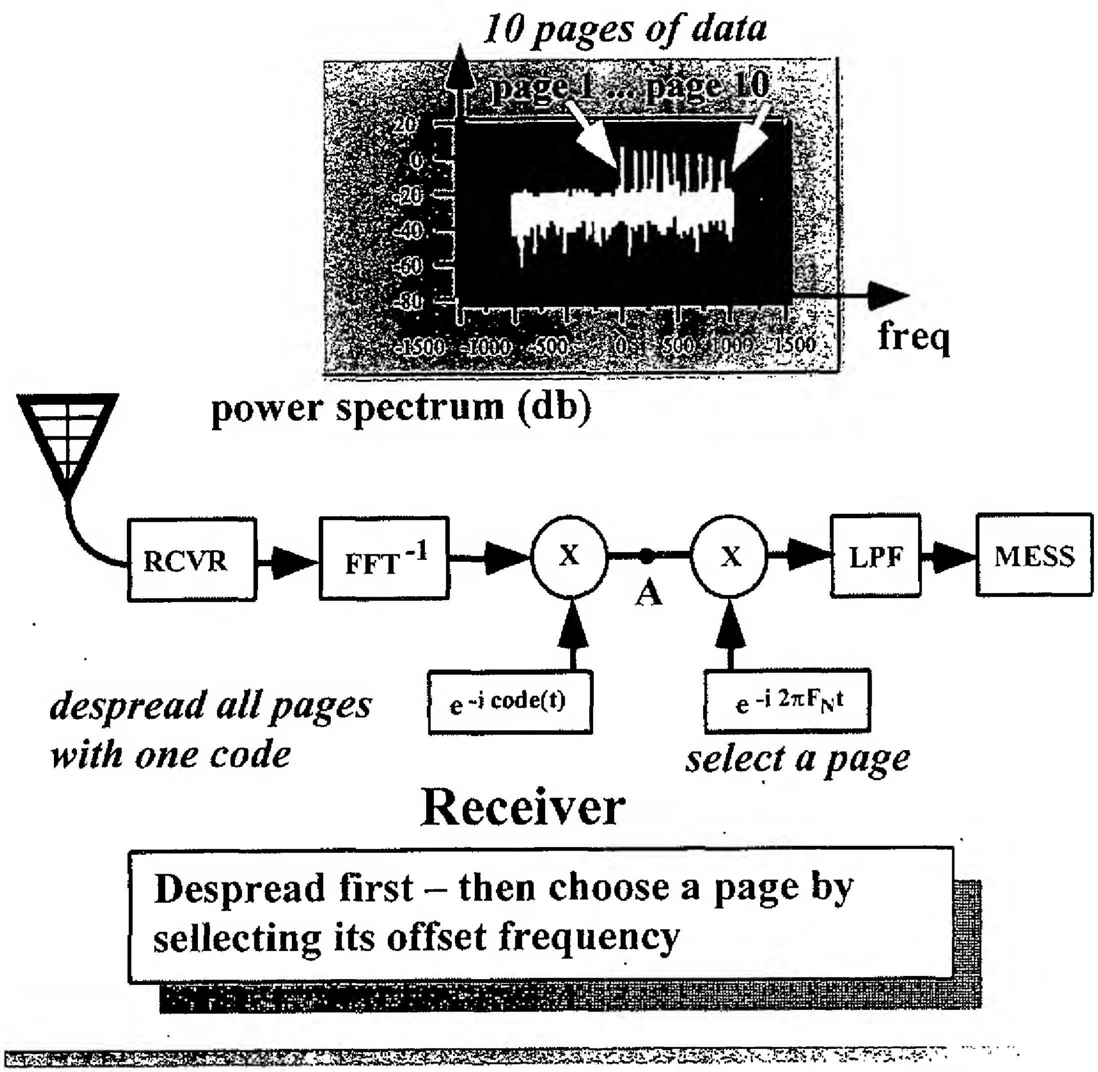
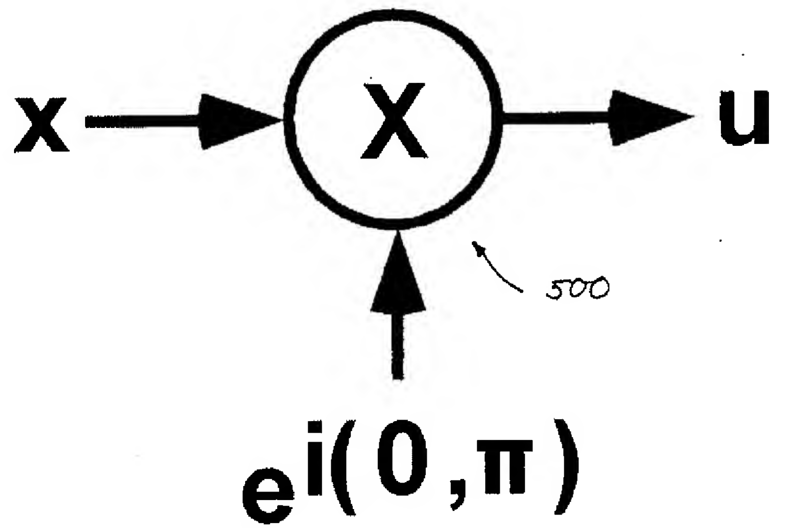

10 pages of data
page 1 ... page 10
20
0
-20
-40
-60
-80
-1500
-1000
-500
0
500
1000
1500
freq
power spectrum (db)
RCVR
FFT -1
X
A
X
LPF
MESS
despread all pages
with one code
e -i code(t)
e -i 2πF_N t
select a page
Receiver
Despread first – then choose a page by
sellecting its offset frequency

Fig. 4b



$$(x)(\mathrm{Cos}(0,\pi)) = u$$

Fig. 5

Fig. 6a

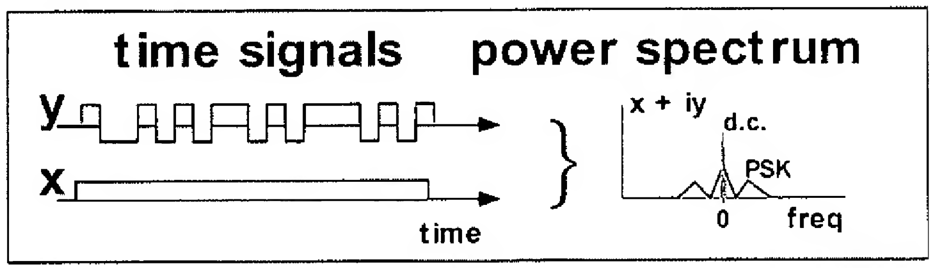
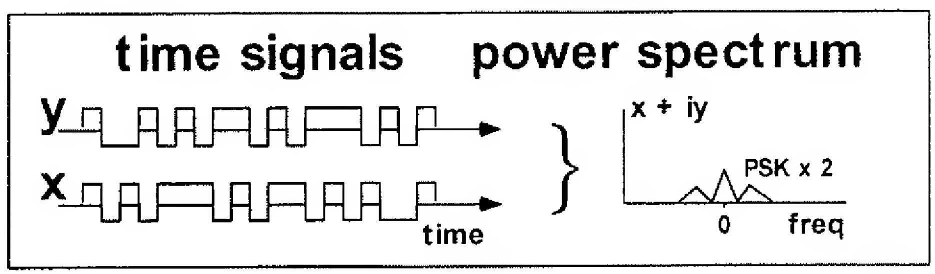

time signals
power spectrum
y
x
time
x + iy
d.c.
PSK
0
freq

Fig. 6b


time signals
power spectrum
y
x
time
x + iy
PSK x 2
0
freq

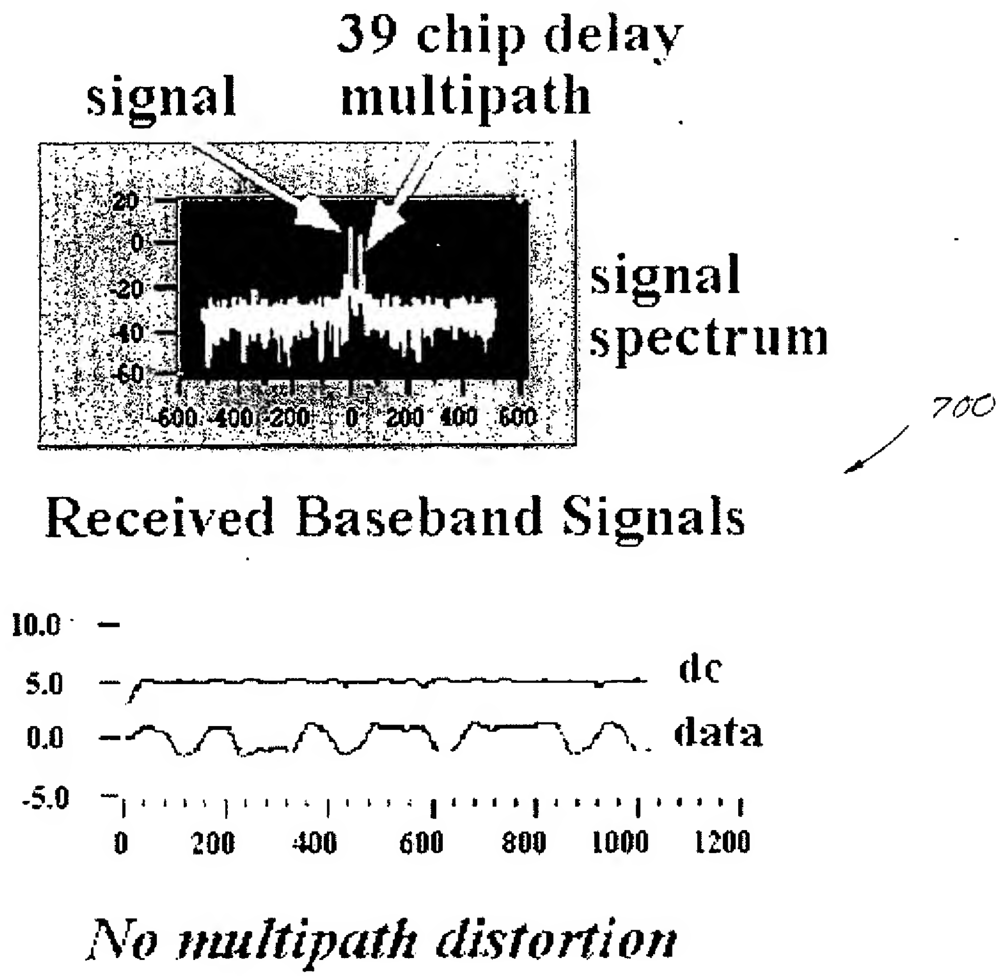

39 chip delay
signal
multipath
20
0
-20
-40
-60
-600
-400
-200
0
200
400
600
signal
spectrum
700
Received Baseband Signals
10.0
5.0
0.0
-5.0
dc
data
0
200
400
600
800
1000
1200
No multipath distortion

Fig. 7

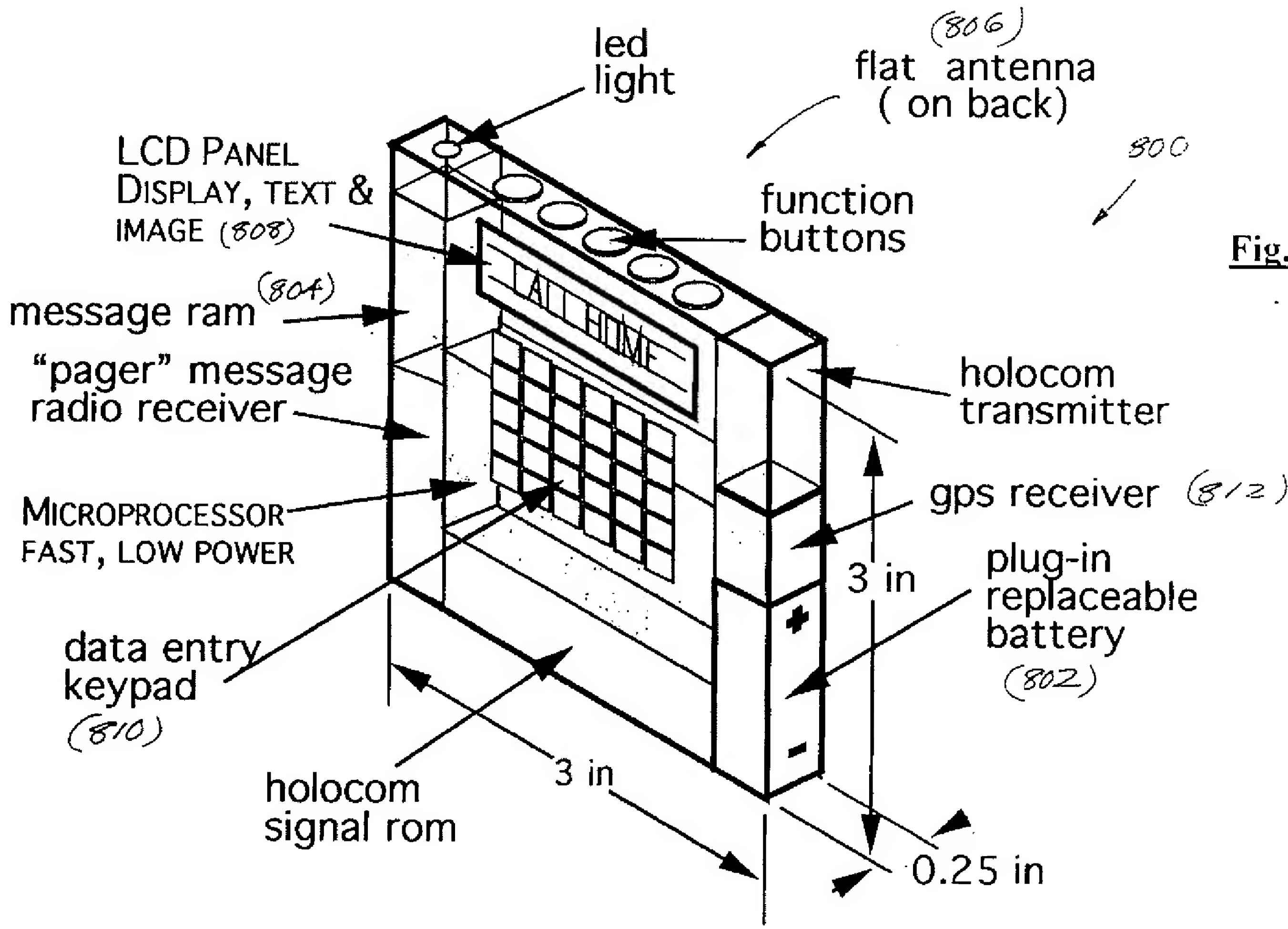

led
light
(806)
flat antenna
(on back)
800
LCD PANEL
DISPLAY, TEXT &
IMAGE (808)
function
buttons
(804)
message ram
"pager" message
radio receiver
CALL HOME
holocom
transmitter
gps receiver (812)
MICROPROCESSOR
FAST, LOW POWER
3 in
plug-in
replaceable
battery
(802)
+
-
data entry
keypad
(810)
holocom
signal rom
3 in
0.25 in

Fig. 8